



5                   **MULTIPLE DYNAMIC CONNECTIVITY FOR SATELLITE  
                    COMMUNICATIONS SYSTEMS**

10           This application claims the benefit under 35 U.S.C  
119(e) of United States provisional application with  
Serial No. 60/266,685 (PD-200277) filed on February 5,  
2001, entitled MULTIPLE LINK FIXED TERMINAL FOR  
GEOSTATINARY COMMUNICATIONS USERS

15                   BACKGROUND OF THE INVENTION

          The present invention relates generally to  
satellite communications systems. More specifically, but  
without limitation thereto, the present invention relates  
to an architecture for communicating between a user  
20   terminal and a communications network via multiple  
wireless communications links.

          In a typical satellite communications system, a  
subscriber terminal transmits information to a hub via a  
satellite using a single forward radio frequency (RF)  
link and receives information from the hub via the  
25   satellite using a single RF return link. If either the  
forward link or the return link is interrupted between  
the satellite and the hub, the terminal is partially or  
totally disabled until another RF link can be  
30   established. Even if another link can be established  
quickly, the interruption in communications may severely  
impair the quality of service for applications such as  
digital television broadcasting. Another disadvantage of  
typical satellite communications systems is that the data  
35   rate is limited to the lowest data rate in the RF link,  
precluding many applications such as digital television.  
Even if higher data rates are available, they generally  
have a higher proportional cost compared to lower data  
rates.

5       become more apparent from the description, presented in  
conjunction with the following drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

10       The above and other aspects, features and  
advantages of the present invention will be more apparent  
from the following more specific description thereof,  
presented in conjunction with the following drawings  
wherein:

15       FIG. 1 is a diagram of a satellite  
communications system based on an Internet protocol  
according to an embodiment of the present invention;

20       FIG. 2 is a diagram of a multiple beam antenna  
(MBA) 200 that may be used for transmitting and receiving  
data frames between the satellites and each of the user  
terminals in FIG. 1;

25       FIG. 3 is a detailed diagram of the user  
terminal of FIG. 1;

30       FIG. 4 is a block diagram illustrating the  
layered software structure of a typical communications  
network of the prior art based on an Internet protocol  
(IP);

35       FIG. 5 is a block diagram illustrating  
demultiplexing of a data stream at the network interface  
level in FIG. 4;

      FIG. 6 is a block diagram illustrating  
demultiplexing at the Internet protocol level in FIG. 4;  
and

      FIG. 7 is a block diagram illustrating  
demultiplexing at the UDP protocol level in FIG. 6.

5 Corresponding reference characters indicate corresponding components throughout the several views of the drawings.

#### DETAILED DESCRIPTION OF THE DRAWINGS

10 The following description is presented to disclose the currently known best mode for making and using the present invention. The scope of the invention is defined by the claims.

FIG. 1 is a diagram of a satellite communications system 100 based on an Internet protocol according to an embodiment of the present invention. Shown in FIG. 1 are geo-stationary satellites 102, RF communications base terminals 104 linking Internet nodes 108 with the geostationary satellites 102, wireless dynamic linkages 105, an Internet 106, and user terminals 110.

The geo-stationary satellites 102 may be, for example, satellites used for digital television systems and for broadband systems such as Spaceway. The geo-stationary satellites 102 may also be transponder platforms such as those used for stratospheric platform based broadband systems. Other types of stationary platforms, such as ground-based stations, may be used as geo-stationary satellites 102 to suit specific applications. In the example of the satellite communications system 100, there are six geo-stationary satellites 102 within the field of view of each of the user terminals 110.

The dashed lines in Fig. 1 indicate exemplary radio frequency (RF) wireless communications linkages 105

5 in a satellite communications system. The wireless communications linkages 105 connect the Internet nodes 108 to each of the user terminals 110 via multiple geo-stationary satellites 102. The wireless communications linkages 105 may be, for example, forward and return  
10 radio frequency (RF) links established in the same manner and with similar equipment used for cellular telephone systems. The actual number and configuration of the radio frequency (RF) wireless communications linkages 105 between the user terminals 110 and the geo-stationary  
15 satellites 102 may change according to traffic conditions and available resources in the geo-stationary satellites 102. The wireless communications linkages 105 in the communications network 100 may therefore be characterized as dynamic.

20 The RF communications base terminals 104 transmit and receive signals between the Internet nodes 108 and the geo-stationary satellites 102 over the wireless communications linkages 105. The RF communications base terminals 104 may be similar to the  
25 equipment used in a base station to establish RF links with users in cellular telephone systems.

One or more Internet nodes 108 may be connected to the geo-stationary satellites 102. Each of the Internet nodes 108 may be, for example, a hub through  
30 which users are connected to the Internet. In this case, the geo-stationary satellites 102 provide last mile connectivity to the user terminals 110. The Internet nodes 108 may each be conveniently located anywhere within the field of view of the corresponding satellite  
35 102.

5           The Internet 106 contains many interconnected  
networks that are based on a data packet transport  
mechanism. Consecutive data packets generated from an  
information source, either from a client computer or from  
a network server, may travel to a designated user  
10 terminal 110 via very different paths. The number of  
routers and servers involved in data packet delivery may  
change dynamically. The number of clients competing for  
the connectivity resource over a hub may vary over time,  
however a user terminal 110 equipped with a multiple beam  
15 antenna (MBA) may continuously provide multiple paths  
connected to various nodes of the Internet 106.  
Applications running on the user terminals 110 can  
therefore communicate concurrently with the Internet 106  
using these multiple paths.

20           The combination of the multiple beam capability  
of the user terminals 110 and the data packet transport  
characteristics via multiple routes in the Internet 106  
ensures uninterrupted communications between the user  
terminals 110 and information sources within the Internet  
25 106.

          User terminals 110 are connected to the  
Internet 106 via geo-stationary satellites 102 and the RF  
communications base terminals 104. The connection of the  
wireless communications linkages 105 may change  
30 dynamically, depending on the traffic load and other  
conditions. The multiple links of the wireless  
communications linkages 105 provide graceful degradation.

          For example, in a single fixed physical connection, data  
transfer is completely interrupted if the physical  
35 connection is broken. Often data is lost as well as time

5 in the process of re-establishing the connection. In the  
present invention, however, data packets may be  
transferred by several wireless communications linkages  
105 concurrently. If one connection is broken, only a  
small number of the data packets are lost that require  
10 retransmission. The retransmission is usually authorized  
by a higher layer protocol and is performed automatically  
through other available links. An important feature of  
packet switched connectivity is that dedicated circuitry  
is not needed to provide continuous connectivity between  
15 geo-stationary satellites 102 and user terminals 110. A  
real connection is established only when a data packet is  
to be delivered; virtual connectivity is always present.

By advantageously exploiting the inherent packet  
switching architecture of the Internet, the real  
20 connectivity resource of geo-stationary satellites 102  
may be shared more effectively among more user terminals  
110.

The bandwidth of the wireless communications  
linkages 105 may also be dynamic. Each of the RF  
25 communications base terminals 104 may have several data  
rates, and the data rates may differ among the RF  
communications base terminals 104, so that the bandwidth  
required by a user terminal 110 is always available. A  
single RF communications base terminal 104 may provide  
30 only a small portion of the total data throughput when  
the quality of a wireless communications linkage 105  
drops, or the RF communications base terminal 104 may  
provide a significant portion of the data throughput when  
the quality of the wireless communications linkage 105  
35 rises. User terminals 110 operate independently from the

5 availability of any single wireless communications linkage 105, rather from a combination of multiple wireless communications linkages 105 operating in parallel concurrently. The multiple wireless communications linkages 105 deliver data packets between  
10 the multiple link terminal 110 and an information source (data server) or sink (client) in the Internet 106.

The Internet 106 may be, for example, the global Internet or any other communications network based on an Internet protocol. Well known Internet protocol  
15 allows currently available routers to be used in the multiple link terminals 110 for both the transmit and receive modes. The Internet infrastructure inherently accommodates data packets or frames arriving by different routes at different times, and Internet protocol ensures  
20 that the data packets are re-arranged at the destination in the proper sequence and are presented in the right format for each specific application.

FIG. 2 is a diagram of a multiple beam antenna (MBA) 200 that may be used for transmitting and receiving  
25 data frames between the geo-stationary satellites 102 and each of the user terminals 110 in FIG. 1. Shown in FIG. 2 are a parabolic reflector 202, feedhorns 204, and a tracking mechanism 206.

The multiple beam antenna (MBA) 200 provides  
30 simple operation at low cost and high performance, however other multiple beam antennas may be used with the user terminal 110 according to techniques well known in the art to suit specific applications. The description of the multiple beam antenna (MBA) 200 below applies to  
35 the receive mode and may be applied reciprocally to the



5 transmit mode. The construction of the multiple beam antenna (MBA) 200 includes the parabolic reflector 202 with a generally one-dimensional array of feedhorns 204.

The multiple beam antenna 200 is oriented so that the array of feedhorns 204 are illuminated by the geo-  
10 stationary satellites 102 along the geo-stationary arc. Using the Ku band, for example, an aperture of about 1.5 meters is adequate for the parabolic reflector 202 to ensure that the beamwidth of illumination is about 1 degree and that the field of view of the multiple beam antenna 200 is about 15 degrees to 20 degrees. The  
15 parabolic reflector 202 allows the illuminating beam to scan to about 10 beamwidths in both directions of the geo-stationary arc. Other techniques may be used to enlarge the field of view if desired according to  
20 techniques well known in the art.

Each of the feedhorns 204 is positioned in the focal plane of the parabolic reflector 202 corresponding to a beam direction pointed at one of, for example, six pre-selected satellite slots of the geo-stationary  
25 satellites 102. The dimensions of the feedhorns 204 and the focal distance of the parabolic reflector 202 are designed to optimize scan loss. Scan loss is defined as the maximum gain loss of a pencil beam scanned from the boresight of the parabolic reflector 202. Boresight is  
30 the beam pointing direction of an illuminating feedhorn 204 located at the focus of the parabolic reflector 202.

In general, the aperture of each of the feedhorns 204 is in the order of one wavelength. The expected peak gain of a beam is about 45 dB at boresight and about 42 dB at  
35 10 degrees off boresight. The 3-dB scan loss is

5 generally acceptable, however, the scan loss may be  
minimized by using well-known techniques. The  
corresponding beamwidths are about 1 degree for the  
boresight beam and 1.3 degrees for the beam at 10 degrees  
off boresight. The outputs of feedhorns 204 may be  
10 connected to low-noise amplifiers according to techniques  
well known in the art.

The tracking mechanism 206 keeps the array of  
the feedhorns 204 pointed at the geo-stationary  
satellites 102. By way of example, each of the feedhorns  
15 204 may be slightly re-positioned and pointed  
independently by well-known mechanical devices such as  
orthogonal jack screws (not shown). Independently  
pointing each of the feedhorns 204 ensures continuous  
correct alignment, but is generally costly to implement.

20 A less expensive approach is to adjust the position of  
the parabolic reflector 202 relative to the entire array  
of feedhorns 204 to optimize the overall data throughput  
for the array of the feedhorns 204. Tracking mechanisms  
for adjusting the position of the parabolic reflector 202  
25 relative to the entire array of feedhorns 204 are well  
known in the art, therefore the tracking mechanism 206 is  
represented in the figure as a simple curved arm  
connecting the feedhorns 204.

FIG. 3 is a detailed diagram of one of the  
30 multiple link terminals 110 of FIG. 1. Shown in FIG. 3  
are received signals 208, amplifiers 304, bandpass  
filters 306, a modulator-demodulator (modem) 308, a  
router & hub 310, a transport layer 314, applications  
316, an estimation processor 318, and external  
35 calibration information 320. The description of the

5 multiple link terminal 110 below applies to the receive mode, and applies reciprocally to the transmit mode.

The amplifiers 304 amplify the received signals 208 corresponding to each of the geo-stationary satellites 102. The bandpass filters 306 remove out-of-  
10 band signals from the amplified received signals 208, which are down-converted and filtered again by down-converters (not shown). The modem 308 converts the resulting waveforms into digital information and extracts the data packets from the Ku-band carrier for each of the  
15 geo-stationary satellites 102.

The router & hub 310 connects the user network links to the Internet 106 via the wireless communications links 105 provided by each of the geo-stationary  
20 satellites 102 and shuffles data packets from various wireless linkages 105 connected via the geo-stationary satellites 102 to the Internet. The router & hub 310 performs the "network" layer functions. The number of available communication linkages to the Internet 106 may be dynamic and is generally limited to less than 10.  
25 Also, there may be more forward links (terminal in receive mode) than return links (terminal in transmit mode), and some of the wireless communication linkages 105 may be bi-directional while others may be uni-directional. The router & hub 310 includes a routing  
30 table that is updated independently for each user terminal 110 by the estimation processor 318. In a geo-stationary satellite system, the routing table content is generally stable. The table dynamics are mainly a result of traffic variations in the user network or Internet and  
35 not of changes in communications topology.

5           The estimation processor 318 inputs the  
external calibration information 320, updates the routing  
table in the router 312, and outputs the relative  
positions of the geo-stationary satellites 102 to the  
tracking mechanism 206 of the multiple beam antenna (MBA)  
10   200 in FIG. 2 and to the routing table in the router &  
hub 310. The estimation processor 318 contains relative  
position vectors for each of the geo-stationary  
satellites 102, user state vectors, satellite state  
vectors, and estimation algorithms.

15           In the transport layer 314, Internet protocol  
ensures that the data packets are re-arranged in the  
proper sequence and are presented in the appropriate  
format to each of the applications 316. TCP/IP protocol  
is generally constructed in layers of modular protocol  
20   software. Each layer is assigned to a task involving the  
message traffic. For example, one layer for the user  
terminal 110 in the receive mode decides whether to keep  
a message or forward it to another application, while  
another layer must decide which application should  
25   receive the message.

FIG. 4 is a block diagram illustrating the  
layered software structure of a typical communications  
network based on an Internet protocol (IP). On the left  
side of FIG. 4, the software layers are illustrated  
30   conceptually as an Internet protocol layer 402 between an  
upper high level protocol layer 404 and a lower network  
interface layer 406. The right side of FIG. 4  
illustrates the software organization of the Internet  
protocol module 408 with respect to multiple high level  
35   protocols 410 and multiple network interfaces 412. This

5 open communications architecture is exploited in the user terminal 110 by using a separate wireless communications link 105 for each of the network interfaces 412.

For example, at the delivery end of the network of a service provider such as a digital TV operator or a multimedia content aggregator using TCP/IP, aggregated data streams intended for a specific user are grouped into datagrams, which are the basic data transfer units in TCP/IP Internet. A datagram is divided into a header and a data section. Internet protocol specifies the header format including the source and destination IP address. Internet protocol does not specify the format of the data section, therefore the data section may be used to transport arbitrary data. The length of the datagram is given by the total length field in the header. Currently the total length field is 16 bits long, and may be changed in the future. For a 16-bit field, the maximum total length of the data section is about 64 kilobits.

Instead of designing datagrams that adhere to the constraints of physical networks, TCP/IP software selects a convenient initial datagram size and arranges a way to divide large datagrams into smaller pieces when the datagram has to traverse a network that has a small maximum transfer unit (MTU), i.e., when the datagram length is greater than the maximum length of a block of data that may be transferred over the network. The smaller pieces into which a datagram is divided are called fragments, and the process of dividing a datagram into fragments is known as fragmentation. Fragmentation usually occurs at a router somewhere along the path

5 between the datagram source and its ultimate destination. When the router receives a datagram from a network with a larger maximum transfer unit to send over a network having a smaller maximum transfer unit, the router fragments the datagram. The fragments travel as separate  
10 datagrams until they arrive at their ultimate destination, where they have to be re-assembled.

At the destination end, datagrams are re-assembled or defragmented from data fragments received over a number of wireless communications linkages 105. If any fragments have been lost, the datagram cannot be re-assembled. When an initial fragment is received by a user, a re-assembly timer is started. If the timer exceeds a specified time limit before all the fragments have been received, the data fragments are discarded and  
20 the datagram is not processed. At a higher layer of the TCP/IP protocol, a re-send signal is initiated for the entire datagram. On the other hand, the datagram would be lost if User Datagram Protocol (UDP) is used. Once a datagram has been fully re-assembled, the data stream may  
25 be demultiplexed at three levels.

FIG. 5 is a block diagram illustrating demultiplexing of a stream of data frames at the network interface level 412 in FIG. 4. At the network interface level 412, demultiplexing of the incoming data frames is  
30 performed based on the frame type field found in the frame header. The frame content following the frame header may be routed to an Internet protocol (IP) module, an address resolution protocol (ARP) module, or a reversed address resolution protocol (RARP) module. The  
35

5 frame header determines which module receives the incoming data frame.

FIG. 6 is a block diagram illustrating demultiplexing in the Internet protocol module of FIG. 5.

When a datagram arrives, an appropriate process is  
10 selected for the datagram based on the protocol type field in the datagram header. The datagram may be classified according to various protocols, for example, TCP (connection oriented), UDP (connectionless oriented), or ICMP (Internet control message protocol). ICMP is  
15 used by a router and host to send reports of problems regarding datagrams to the originator, including echo request and reply, and EGP (exterior gateway protocol). EGP is used by a router in one autonomous system to advertise the IP addresses of networks within that  
20 autonomous system to a router in another autonomous system.

FIG. 7 is a block diagram illustrating demultiplexing by the UDP protocol module in FIG. 6. In this example, a UDP destination port number is used to  
25 select an appropriate destination port for incoming datagrams. A socket uniquely represents an IP address plus a port number. Connections between two hosts are specified fully by sockets assigned to the datagram originator and the destination. Connections between two  
30 sockets are full duplex communication paths between end processes. TCP identifies a connection as a pair of endpoints; UDP uses port numbers. TCP provides reliable datagram delivery service, UDP does not. Each of these protocols is used in various applications.

5           The user terminal 110 described above may be  
used for broadband last mile connectivity to connect  
multiple subscribers to the Internet, advantageously  
providing multiple wireless connections in a physical  
layer. The multiple wireless connections support various  
10 applications concurrently with robust and dynamic  
interconnectivity and may be used to increase system  
capacity limited by satellite slots and available  
bandwidth. A broad spectrum of digital multimedia  
services including satellite digital TV systems, such as  
15 DirecTV, may be provided using existing satellites while  
eliminating the single point failure problem presently  
confronting all satellite systems. By breaking the  
barrier of capacity limitation, the multiple terminal  
link 110 of the present invention enables a multimedia  
20 service provider to deliver multi-casting services more  
effectively.

Other modifications, variations, and  
arrangements of the present invention may be made in  
accordance with the above teachings other than as  
25 specifically described to practice the invention within  
the spirit and scope defined by the following claims.